GEOTHERMAL ENERGY CONVERSION SYSTEMS FOR EGS RESOURCES

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1. What was our part in the analysis?

- **To select energy conversion (EC) systems appropriate for EGS.**
- **To carry out parametric analyses for these systems.**
- **To estimate the installed cost of the EC systems.**

2. What were our specific objectives?

To carry out the above objectives for the following EGS fluid temperatures:

100 ºC 150 ºC 200 ºC 250 ºC 400 ºC

For each case, to determine:

- **Expected net power per unit of mass flow (kW/(kg/s)).**
- **Mass flows of EGS fluid for plant ratings of 1, 10 and 50 MW.**
- **Plant costs per installed power ($/kW).**

3. How did we perform our portion of the analysis?

- **Various types of standard and non-standard EC systems were reviewed including:**

  Binary; Single- and Double-Flash; High-Pressure, Triple-Flash and Single-Expansion.

- **Thermodynamic analysis was performed using state-of-the-art fluid properties.**

- **Cost figures were developed based on a model from *GeothermEx*, and adapted to fit our application.**

4. What was the basis for our analysis, including assumptions?

A. For Binary-type plants:

- Used for lower-temperature EGS fluids: 100°C - 180°C.
- EGS fluid was maintained in a liquid phase from production well to plant to injection well.
- Thermal efficiency was determined by correlating existing plant data with a simple linear regression formula.

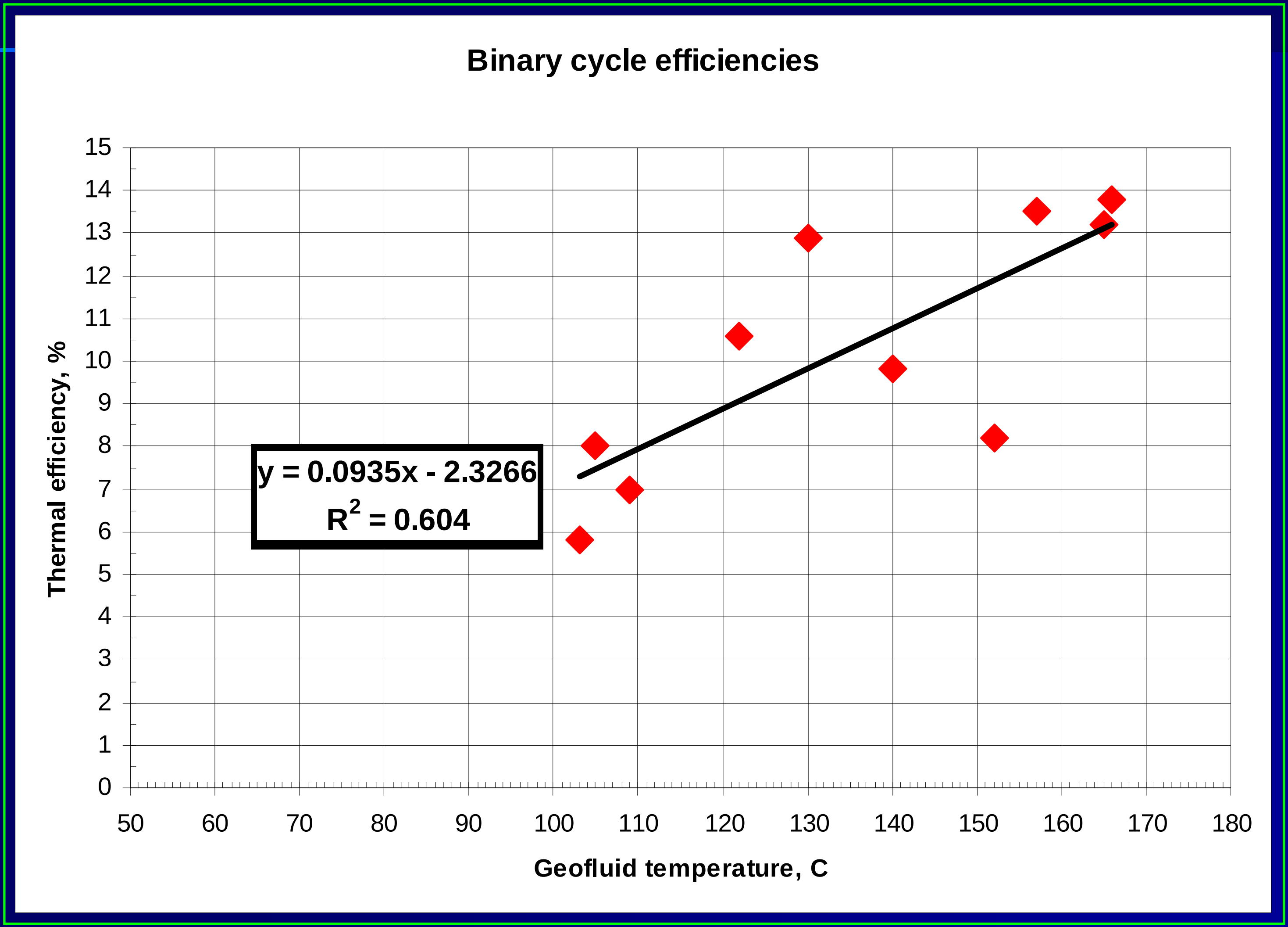
- A complete example design was prepared for a 1 MW plant using co-produced fluids at the NPR No. 3, using the design software package of Barber-Nichols.

Binary plant thermal efficiency

T-fluid, °C	Effic., %	Plant name and location
103	5.8	Amedee, CA
105	8	Wabuska, NV
109	7	Brady Bottoming Cycle, NV
122	10.6	Husavik Kalina, Iceland
130	12.9	Otake Binary, Japan
140	9.8	Nigorikawa, Japan
152	8.2	Steamboat SB-2 & SB-3, NV
157	13.5	Ormesa II, CA
165	13.2	Heber SIGC, CA
166	13.8	Miravalles Unit 5, Costa Rica

GEOTHERMAL POWER PLANTS

Binary plant efficiency correlation



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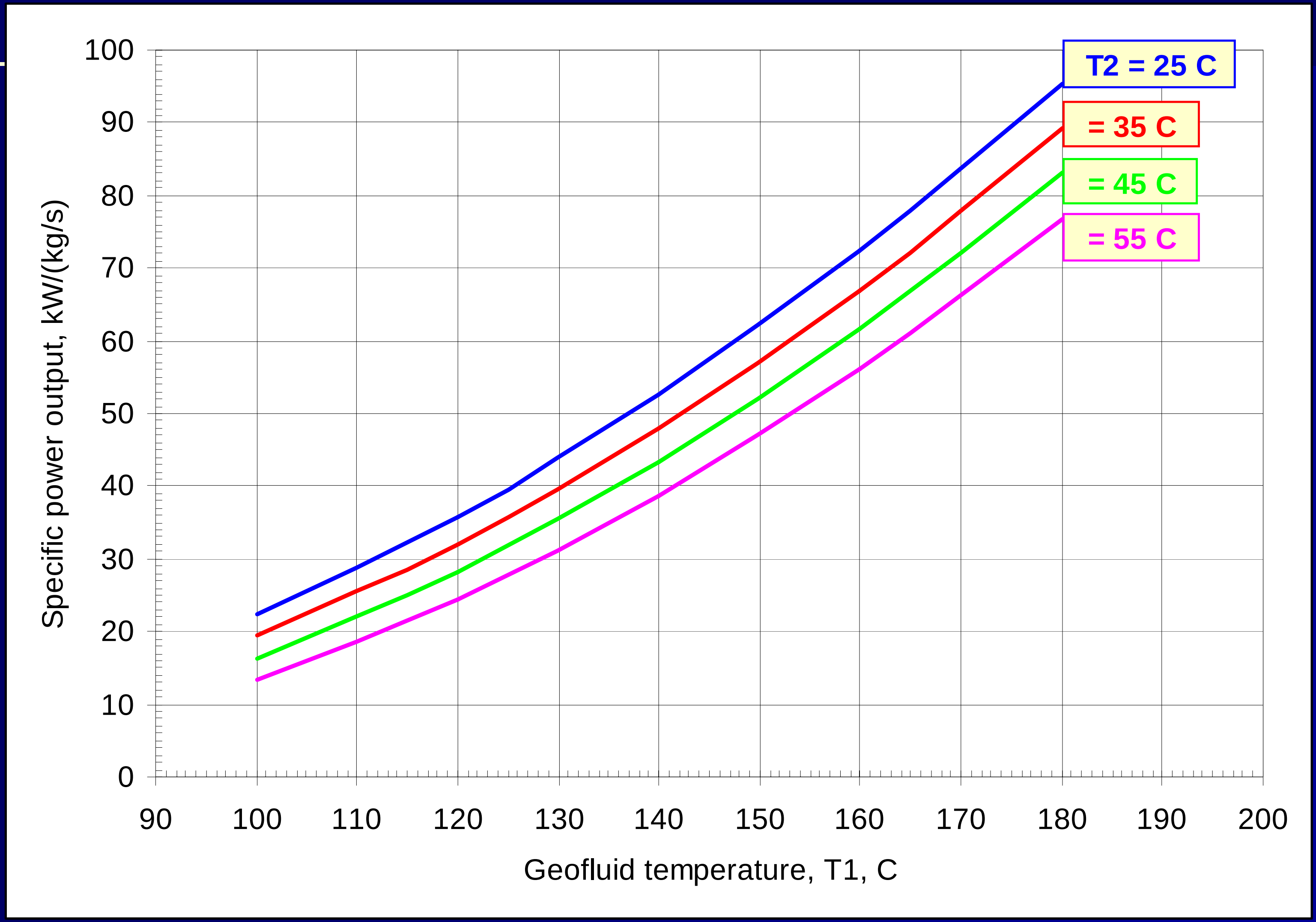
Binary plant specific power output



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B. For Flash-type plants:

- Used for moderate-to-high temperature EGS fluids: 200ºC - 250ºC.
- EGS fluid was separated into steam and liquid, and flashed, if appropriate.
- Turbine efficiencies were based on the Baumann rule which lowers the turbine efficiency by 1% for each 1% of average moisture present during the expansion process; a dry efficiency of 85% was selected.

4. What was the basis for our analysis, including assumptions?

C. For High-Pressure, Triple-Flash & Single-Expansion-type plants:

- **Used for supercritical EGS fluids: 400ºC.**
- **For moderately-high pressures EGS fluids, a topping SC turbine was used with a Double-Flash EC, forming a Triple-Flash system.**
- **For the highest EGS fluid pressures, the fluid was throttled and then expanded through a steam turbine, resulting in a Single-Expansion system.**

$C = 750 + 1125 \times \exp(-0.006115(\dot{W} - 5))$

4. What was the basis for our analysis, including assumptions?

D. For plant costs:

***GeothermEx*-based (Sanyal) plant-cost formula:**

$$C = 750 + 1125 \times \exp(-0.006115(\dot{W} - 5))$$

where cost is in $/kW and the plant power capacity is in MW.

Thus, a 5 MW plant will cost $1,875/kW and large units or large numbers of similar plants will have an asymptotic cost of $750/kW.

5. What would we consider to be the major uncertainties?

- Plant costs are the most uncertain pieces of our analysis.
- The thermodynamic analyses are solidly based on reasonable technical assumptions.
- The "learning curve" nature of the cost formula may be optimistic.
- The "long-term" asymptotic cost was our judgment based on experience.

6. How did we deal with the uncertainties, and how might those uncertainties have affected the outcome of the analysis?

- **We presented the results in parametric form, giving ranges of power outputs and plant costs for various conditions that might be encountered.**

- **If newer cost data becomes available, our figures can be adjusted since the cost equation has three parameters that can be modified to match new data.**

7. What technology gaps and barriers need to be overcome within our specific area?

In the expected EGS fluid temperature range of 150-200^{o}C, the EC systems should be “off-the-shelf”.

8. What technology options will fill the gaps and overcome the barriers?

If high-temperature, high-pressure supercritical EGS fluids are produced, then research and development on high-pressure, total-flow expansion machines would be needed to raise the efficiency of EC systems for these fluids.

Our EC system used a lossy throttling process that is inexpensive but inefficient to lower the EGS fluid pressure to reasonable levels for use in a conventional turbine.

Thanks for your attention.

***Are there any more questions and/or
further discussion?***